



**EPRI Results Summary:**  
**A Case Study Assessment of Trace Metal Atmospheric Emissions  
and Their Aquatic Impacts in the San Juan River Basin**

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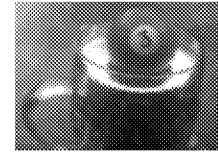
**Joel Herr**  
Systech Water Resources

**Albuquerque**  
August 8, 2013

## EPRI San Juan Basin Project Goals

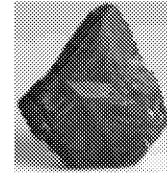
- Integrated assessment of atmospheric inputs and watershed concentrations of trace metals
- Identification of mercury contributions to fish tissue by source category
- Accounting for accumulation over time, slow movement of substances
- Reasonable projections of future actions and their outcomes
- *Outcomes sought:*
  - Time series
    - Fish tissue mercury levels in top predators, by source, for a range of source scenarios
    - Water column selenium, arsenic from 3 nearby sources
  - Source attribution: Fish tissue mercury changes
- *Not* carrying out assessment vs. wildlife criteria (ERA). Results transferred to other research groups for use in assessments.

# Key Points About Mercury Dynamics



- Complex transitions between inorganic, organic forms
  - In atmosphere (after emission):
    - Most emissions are elemental mercury = GEM form
    - Oxidation-reduction reactions between elemental and oxidized = ionic = divalent = GOM (“gaseous oxidized mercury”) form
  - Removal from atmosphere:
    - Elemental Hg: nearly insoluble in water (precipitation), so transported very long distances (continental), may oxidize to GOM
    - Oxidized Hg: soluble in precipitation, “washes out” of atmosphere, tends to deposit closer to sources
  - Upon reaching the surface/surface waters:
    - Divalent mercury is reactive, small portion converted to organic form (mostly “methylmercury” = monomethylmercuric chloride)
    - Methylmercury taken up by aquatic organisms, food web, bioaccumulates to x1000s in concentration

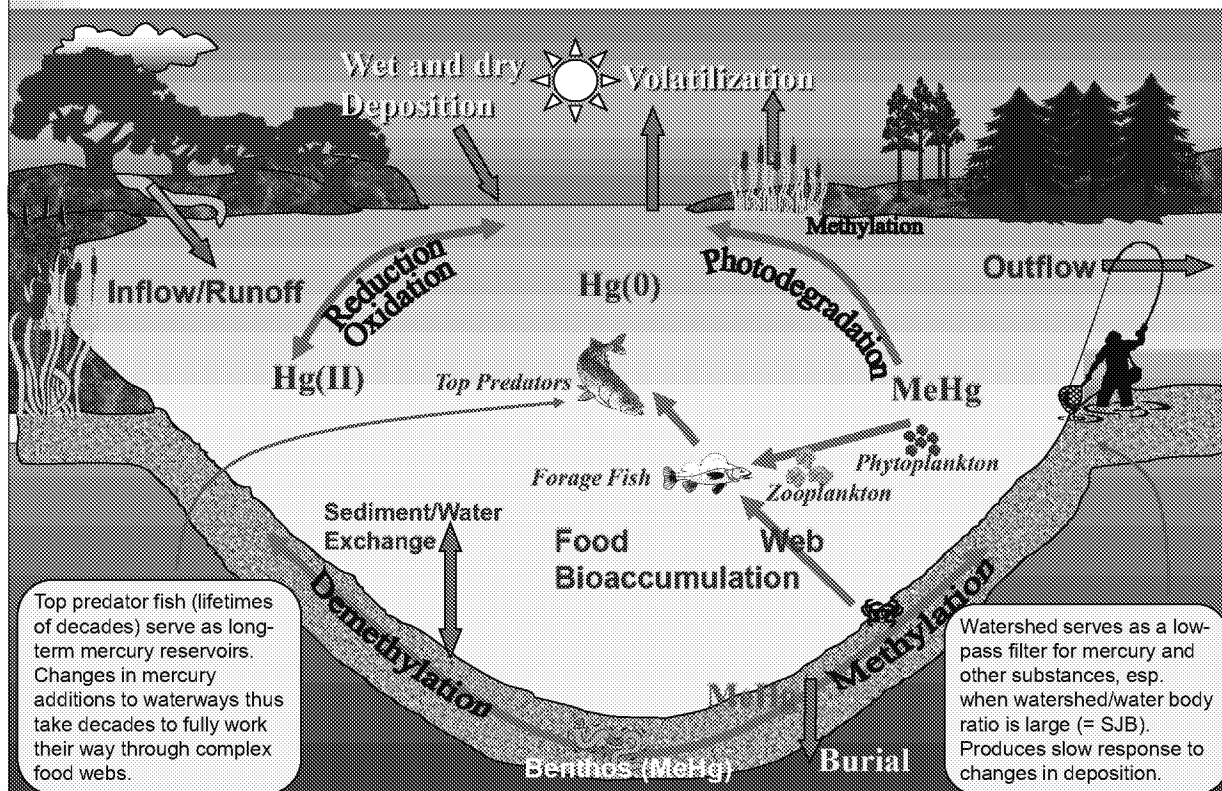
*Cinnabar ore  
(mercuric  
sulfide)*



*monomethylmercury*



# The Complex Aquatic Dynamics of Mercury



# Modeling Tools Used in the Analysis

## GEOS-Chem → CMAQ-APT

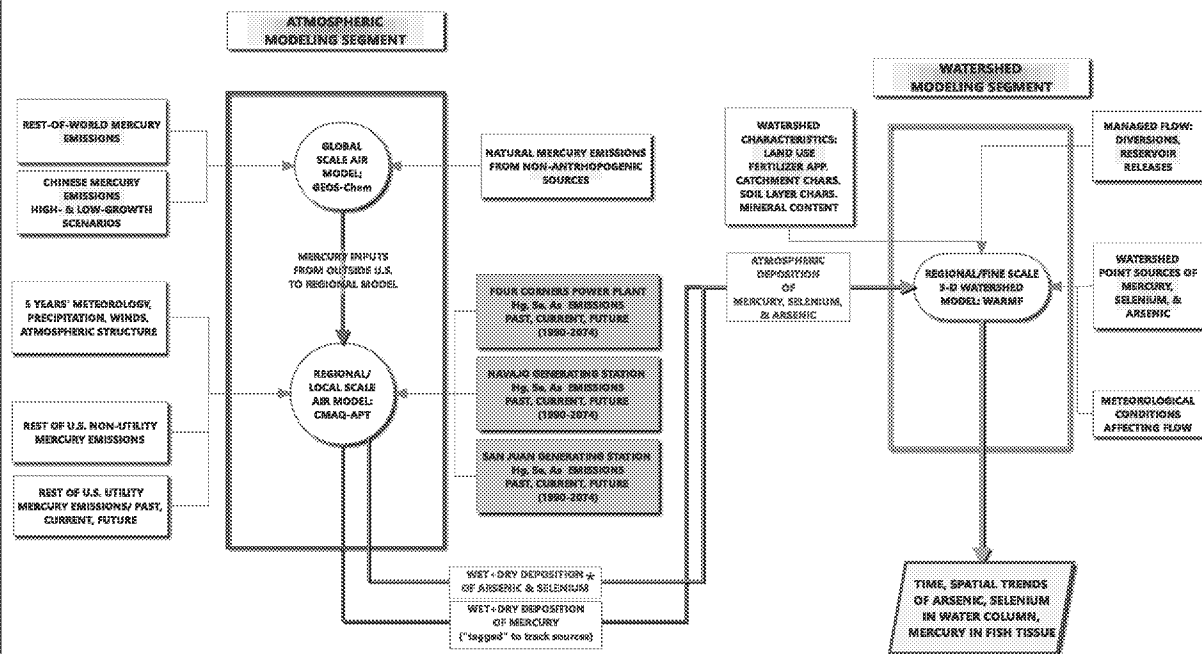
- **GEOS-Chem:** A global-scale model, developed by NASA and Harvard
- **CMAQ-APT:** A regional/local-scale air quality transport/chemistry model, developed by EPA and EPRI
- **Input:** Atmospheric emissions data from point and non-point sources, meteorological data
- **Output:** Wet & dry atmospheric deposition of pollutants



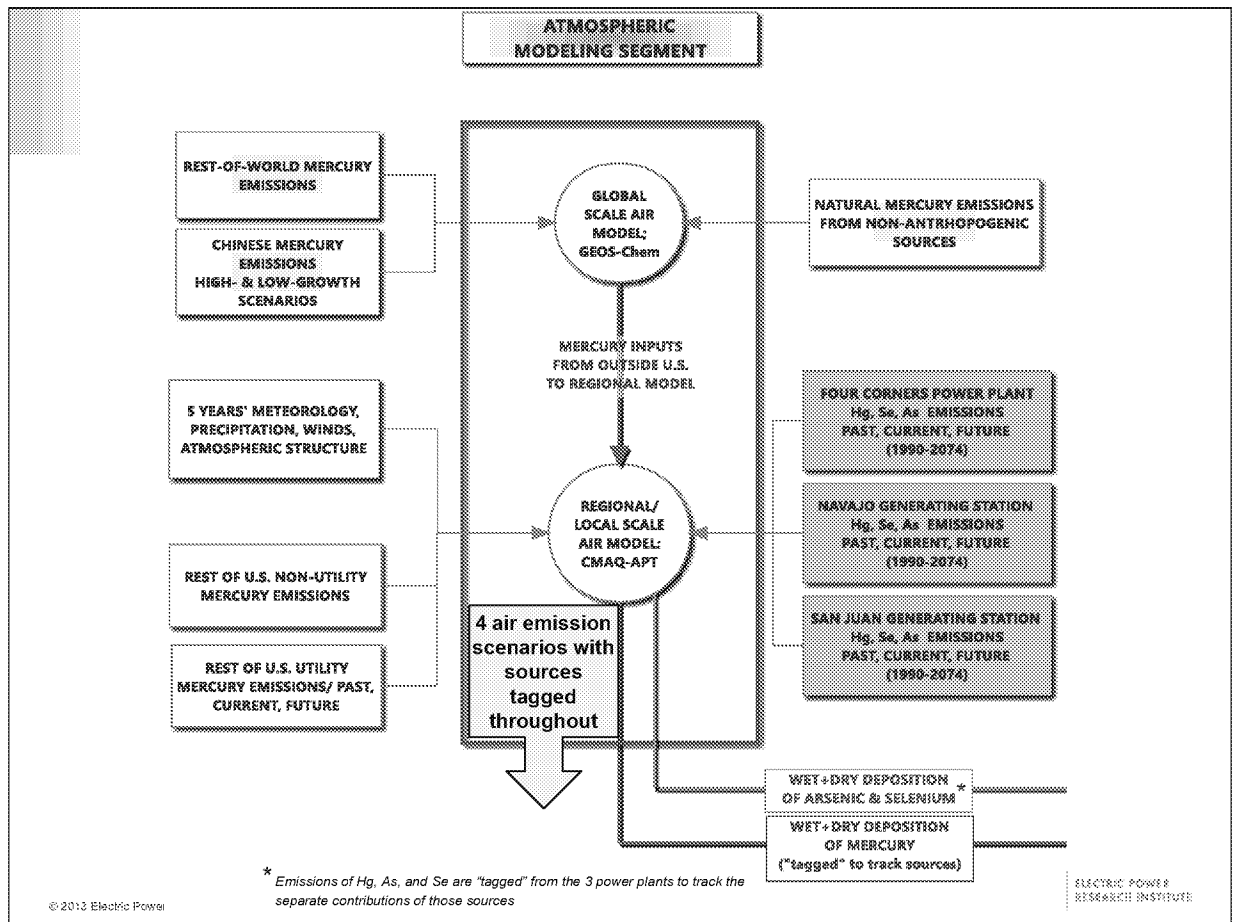
## Watershed Analysis Risk Management Framework (WARMF)

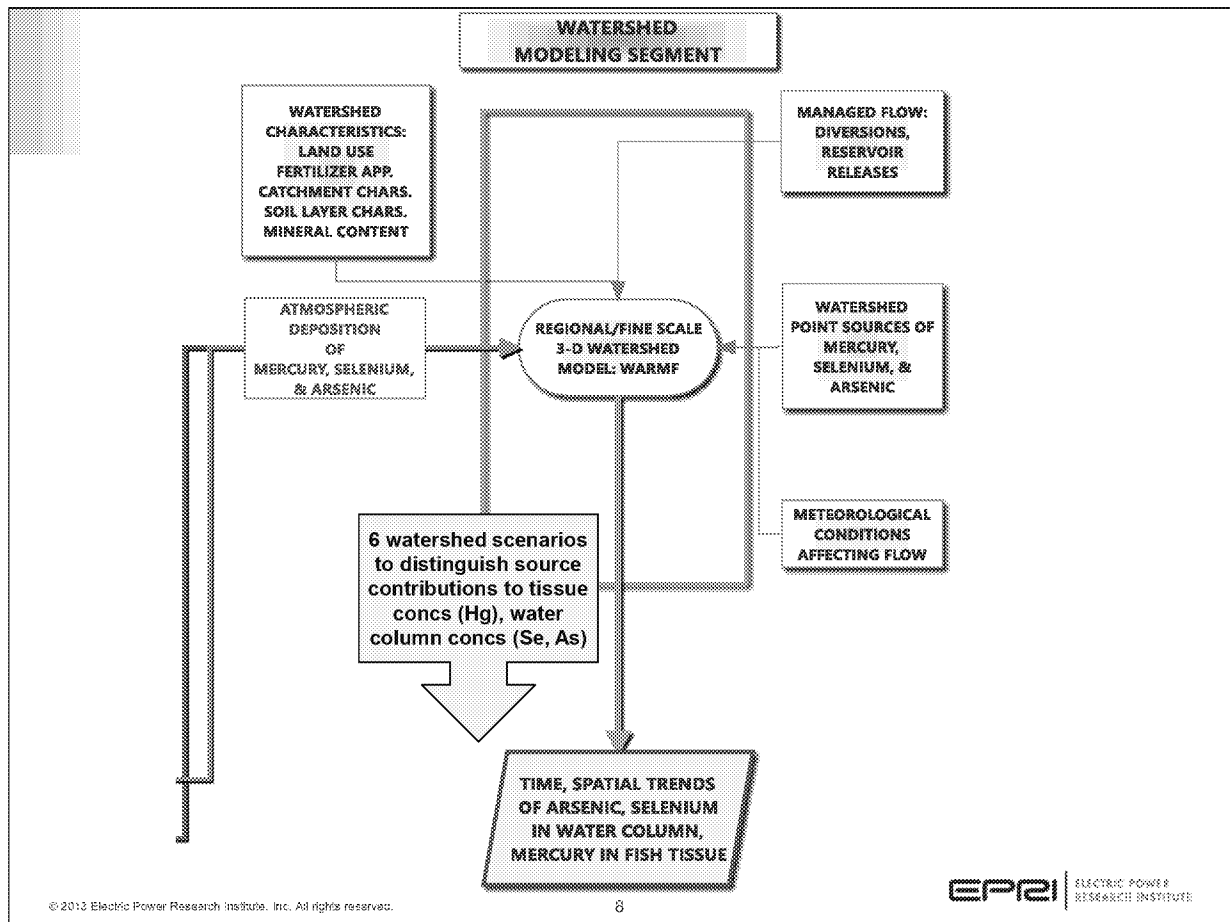
- A hydrology/water quality model, developed by Systech/EPRI
- Handles aquatic chemistry/biochemistry of mercury, other constituents
- **Input:** Wet & dry atmospheric deposition, meteorology, topography, soil data, point sources, diversions
- **Output:** Water quality (mercury, selenium, and arsenic concentrations), stream flow, concentrations of mercury in fish

# EPRI Air-Watershed Analysis



\* Emissions of Hg, As, and Se are "tagged" from the 3 power plants to track the separate contributions of those sources







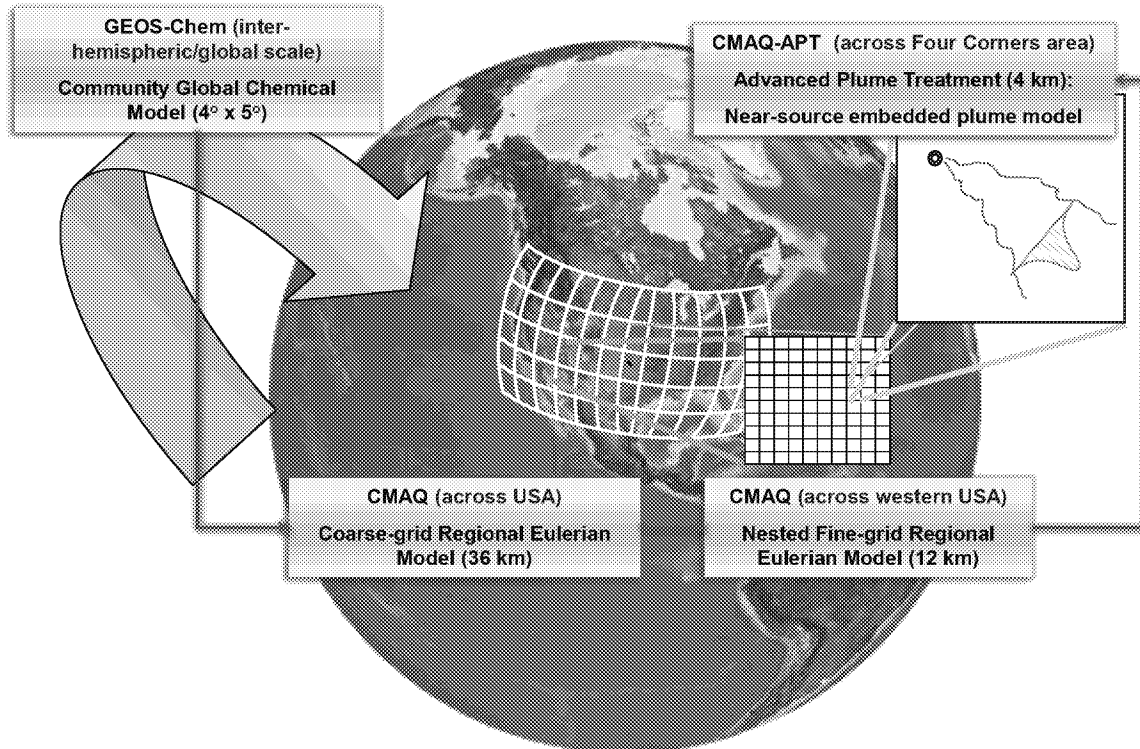
# **Atmospheric Emissions and Deposition Modeling**

Krish Vijayaraghavan  
ENVIRON

## Historical and Future Atmospheric Deposition Record for Watershed Scenarios

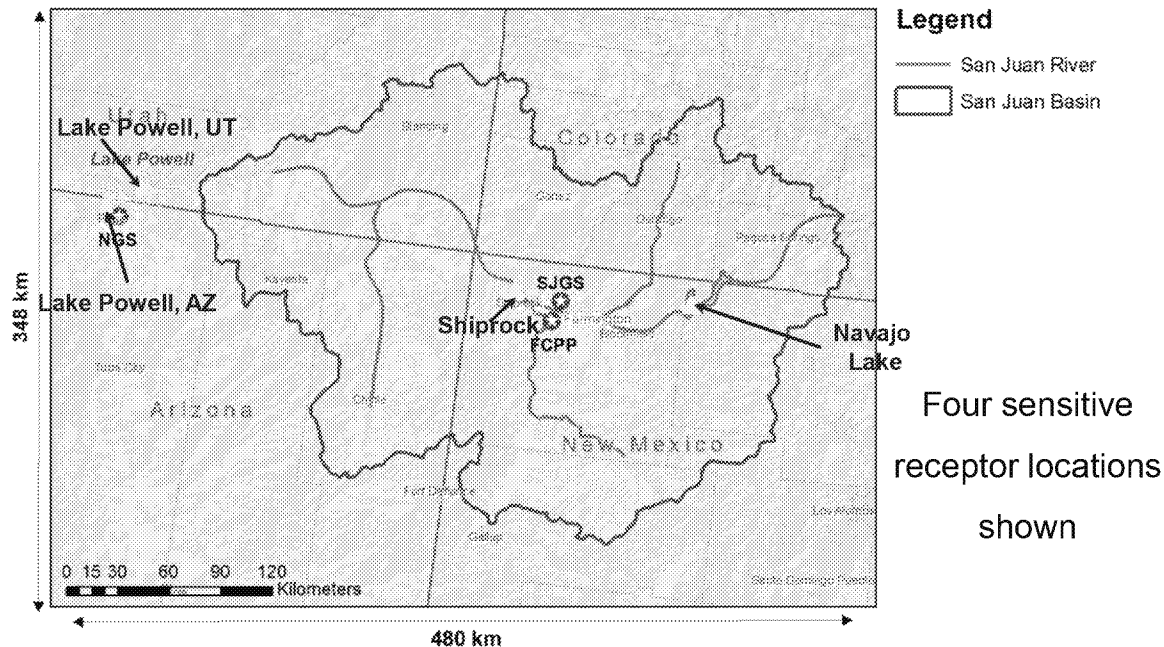
- Time Period: 1990 – 2074
- Annual mercury deposition calculated due to temporally varying emissions from:
  - Four Corners Power Plant (FCPP)
  - Navajo Generating Station (NGS)
  - San Juan Generating Station (SJGS)
  - Other sources in Four Corners domain
  - Other sources in USA
  - China sources
  - Other global sources
- Annual arsenic and selenium deposition calculated due to temporally varying emissions from FCPP, NGS and SJGS

# Air Modeling: Global, Regional and Local Scale



Multi-scale modeling conducted due to observational evidence of long-range transport of Hg

# Local-scale Air Modeling Domain



# Air Source Emissions Modeling Scenarios

## ❖ Approach

- ☐ Source emissions of Hg, Se, As are “tagged” to allow contribution of each to be identified in deposition to the watershed
- ☐ Allows 4 air source scenarios to provide input to many watershed scenarios

## ❖ Air source emissions scenarios

- ☐ Baseline (pre-MATS) scenario
  - Source emissions are set to represent the period from 1990\* to present
  - Used for build-up of slow-circulating constituents in the watershed
- ☐ Post-MATS scenario
  - Represents post-2016 period (2014 in case of FCPP)
- ☐ High China growth scenario (2050 A2 case) \*\*
  - Chinese elemental Hg emissions increase 2032–2050 → increasing China deposition in U.S.
- ☐ Low China growth scenario (2050 B2 case) \*\*
  - Chinese elemental Hg emissions decrease 2032–2050 → declining China deposition

\* 1990 is start of watershed simulations

\*\* China scenarios apply only to mercury

# Changes in Local Power Plant Emissions

## ❑ Four Corners Power Plant

- 1990 – 2013: 5 units operational
  - Hg = 518 lb/yr, As = 76 lb/yr, Se = 1412 lb/yr
  - 3 units retired at the end of 2013
- 2014 – 2041: 2 units operational
  - Hg = 102 lb/yr, As = 50 lb/yr, Se = 425 lb/yr
- 2042 – 2074: FCPP shut down

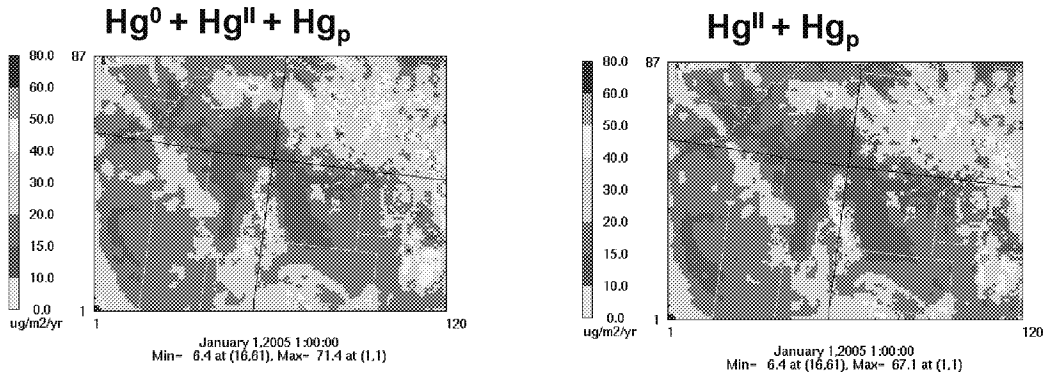
## ❑ Navajo Generating Station

- 1990 – 2015: 3 units operational with pre-MATS controls
  - Hg = 472 lb/yr, As = 259 lb/yr, Se = 4370 lb/yr
- 2016 – 2044: 3 units operational with post-MATS controls
  - Hg = 228 lb/yr, As = 259 lb/yr, Se = 4370 lb/yr
- 2045 – 2074: NGS shut down

## ❑ San Juan Generating Station

- 1990 – 2015: 4 units operational with pre-MATS controls
- 2016 – 2074: 4 units operational with post-MATS controls

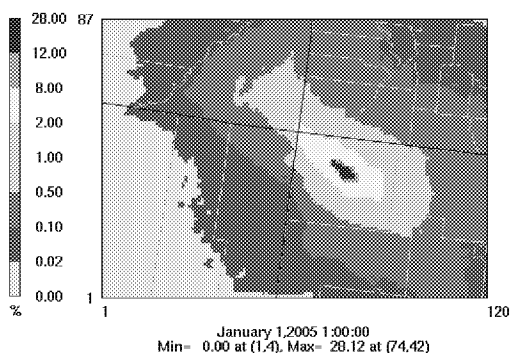
# Annual wet + dry Hg deposition in baseline case



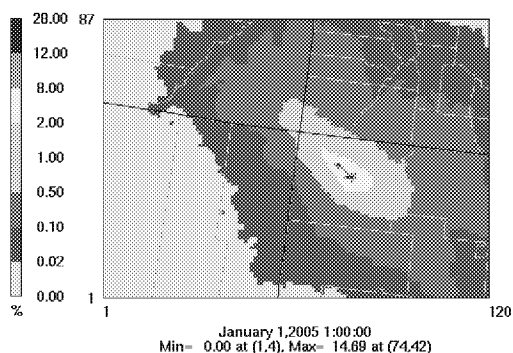
- $\text{Hg}^{2+} + \text{Hg}_p$  deposition > 90% of total deposition of all forms of Hg
- Dry deposition of  $\text{Hg}^{2+} + \text{Hg}_p$  typically > 70% of dry + wet deposition
- Model compares well with observations at Mesa Verde National Park
  - Wet deposition within 14% of MDN measurements (under-prediction)
  - Dry deposition within 34% of EPA measurements (over-prediction)
  - Total deposition within 11% (over-prediction)
- Average Hg deposition over San Juan basin  $\sim 20 \mu\text{g}/\text{m}^2/\text{yr}$
- Subsequent discussion focuses on  $\text{Hg}^{2+} + \text{Hg}_p$  (main forms of Hg that methylate)

# Contribution of Four Corners Power Plant to mercury deposition, baseline & post-MATS cases

**Baseline**



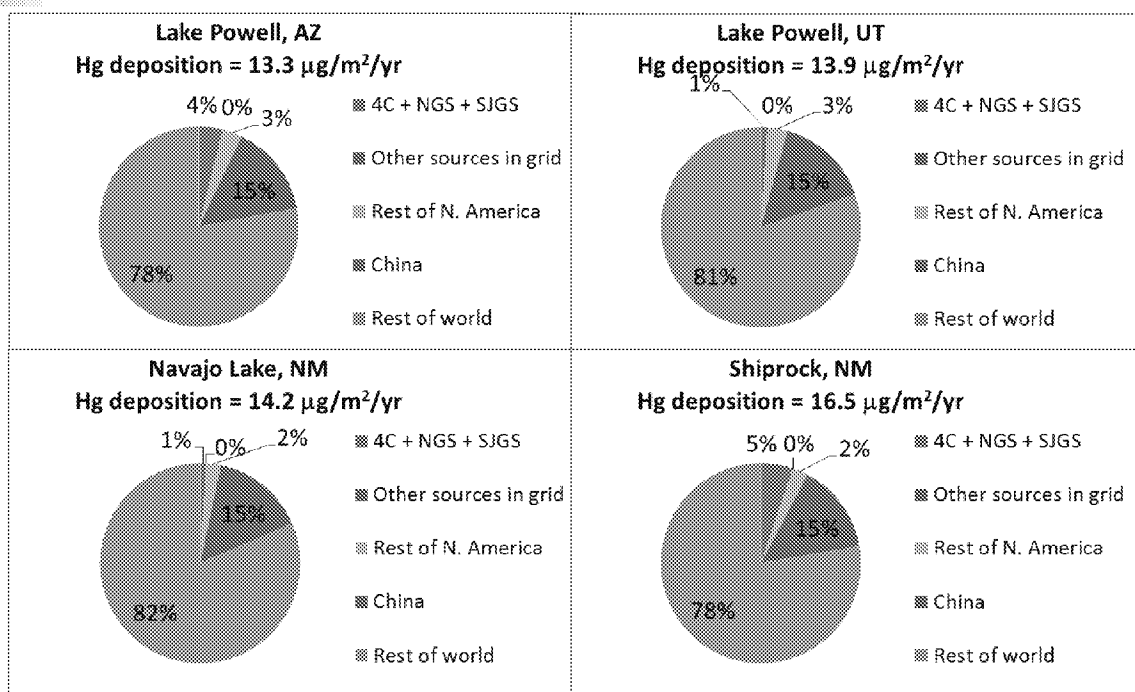
**Post-MATS**



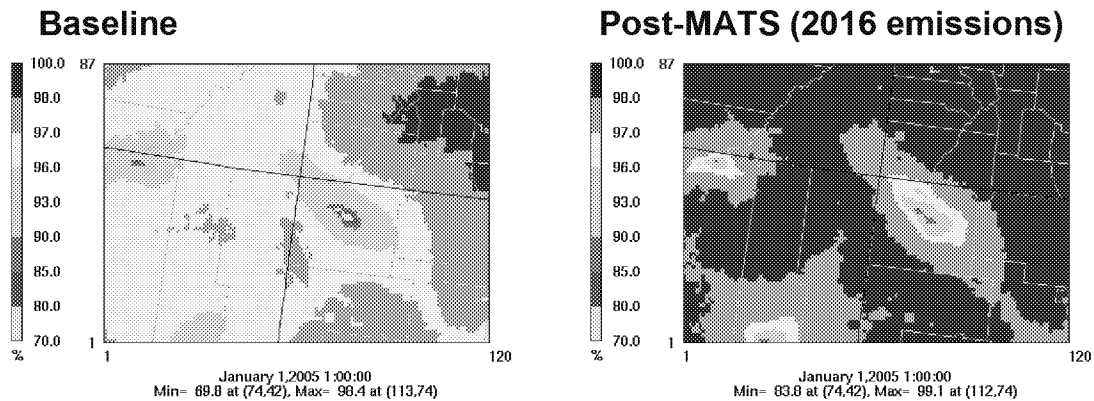
- In baseline case, FCPP contributes < 2% of total Hg deposition over most of the San Juan basin and up to 28% near the plant
- After retirement of units 1-3, FCPP contributes < 2% over most of the San Juan basin and up to 15% near the plant



## Relative contribution of mercury sources to deposition at receptor locations, baseline case

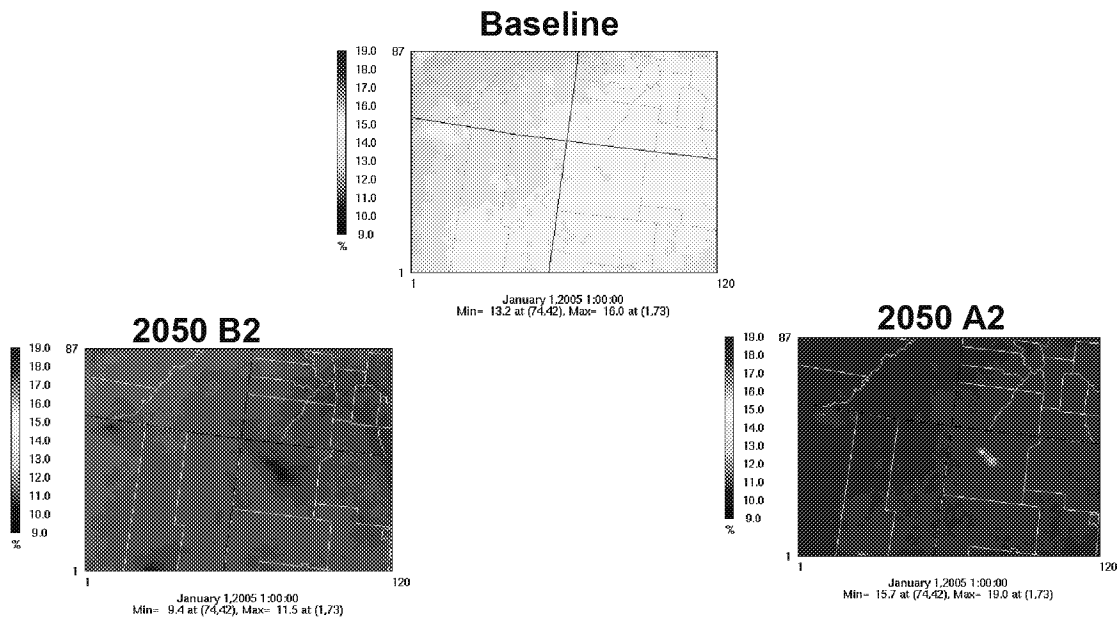


# Contribution of non-US sources to mercury deposition in baseline and post-MATS cases



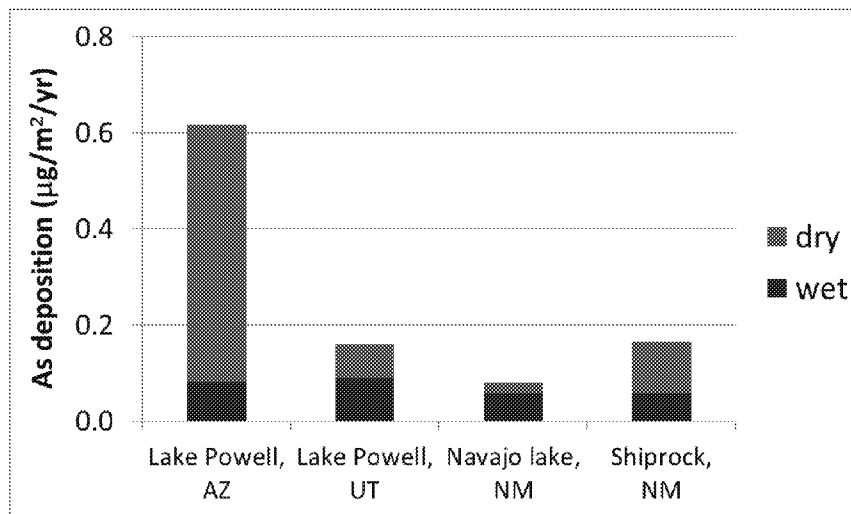
- In baseline case, non-US sources contribute at least 69% of total Hg deposition everywhere in the San Juan basin
- After 2016, non-US sources contribute at least 83% of total Hg deposition everywhere in the San Juan basin (higher than baseline due to reductions in US power plants and other sources)

# Contribution of Chinese sources to mercury deposition in post-MATS, 2050 A2, 2050 B2 cases



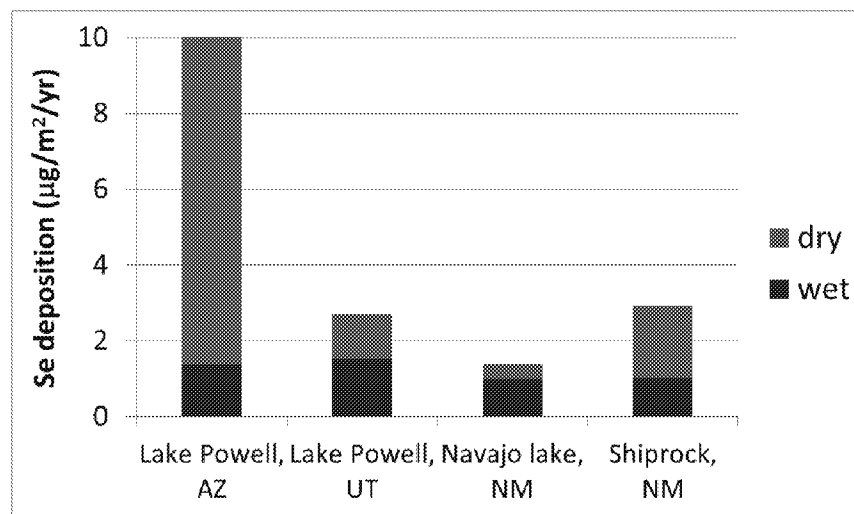
- Chinese sources contribute up to 12% of total Hg deposition in low China case, up to 16% in baseline and up to 19% in high China case

## Arsenic deposition due to the three local power plants at four receptor locations in baseline case



- Either dry or wet deposition could dominate depending on location
- Limited measurements of total arsenic deposition in USA
  - Dry + wet measured As deposition = 101 to 703  $\mu\text{g}/\text{m}^2/\text{yr}$  along the mid-Atlantic coast (Scudlark et al., 1998) and

## Selenium deposition due to the three local power plants at four receptor locations in baseline case



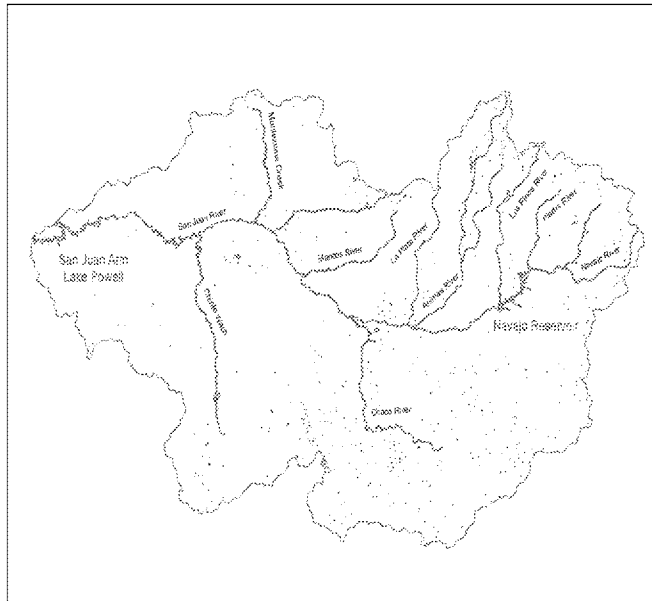
- Either dry or wet deposition could dominate depending on location
- Limited measurements of total selenium deposition in USA
  - Measured dry + wet selenium deposition =  $45 \mu\text{g}/\text{m}^2/\text{yr}$  in Delaware (Wen and Carignan, 2007)

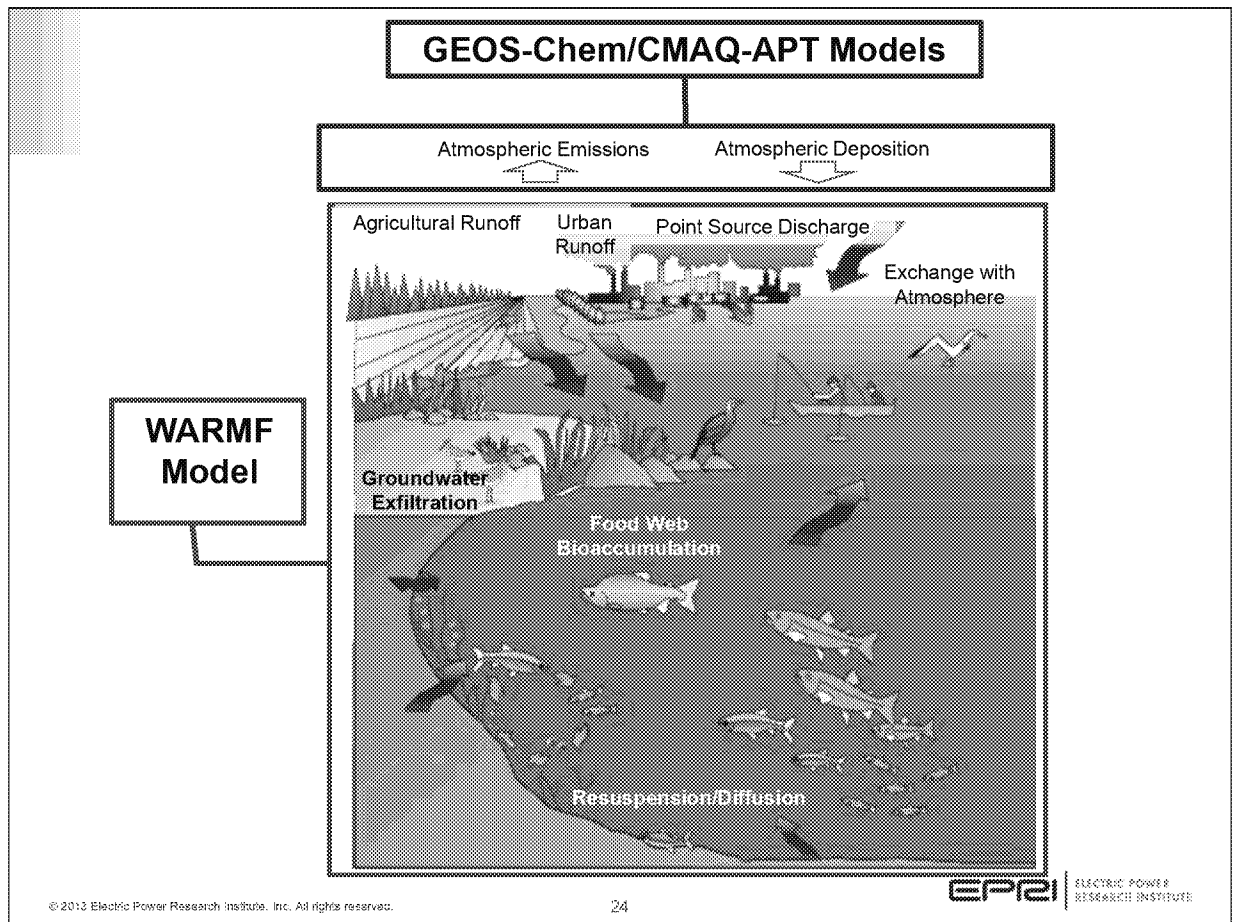
# **Watershed and Ecosystem Modeling**

Joel Herr  
Systech

## Project Area

- 25, 000 square miles / 16 million acres
- Three coal-fired power plants
- Multiple surface reservoirs
- Critical habitat for endangered fish





Talk about the relevant components of each model and how AMSTERDAM provides WARMF with input.

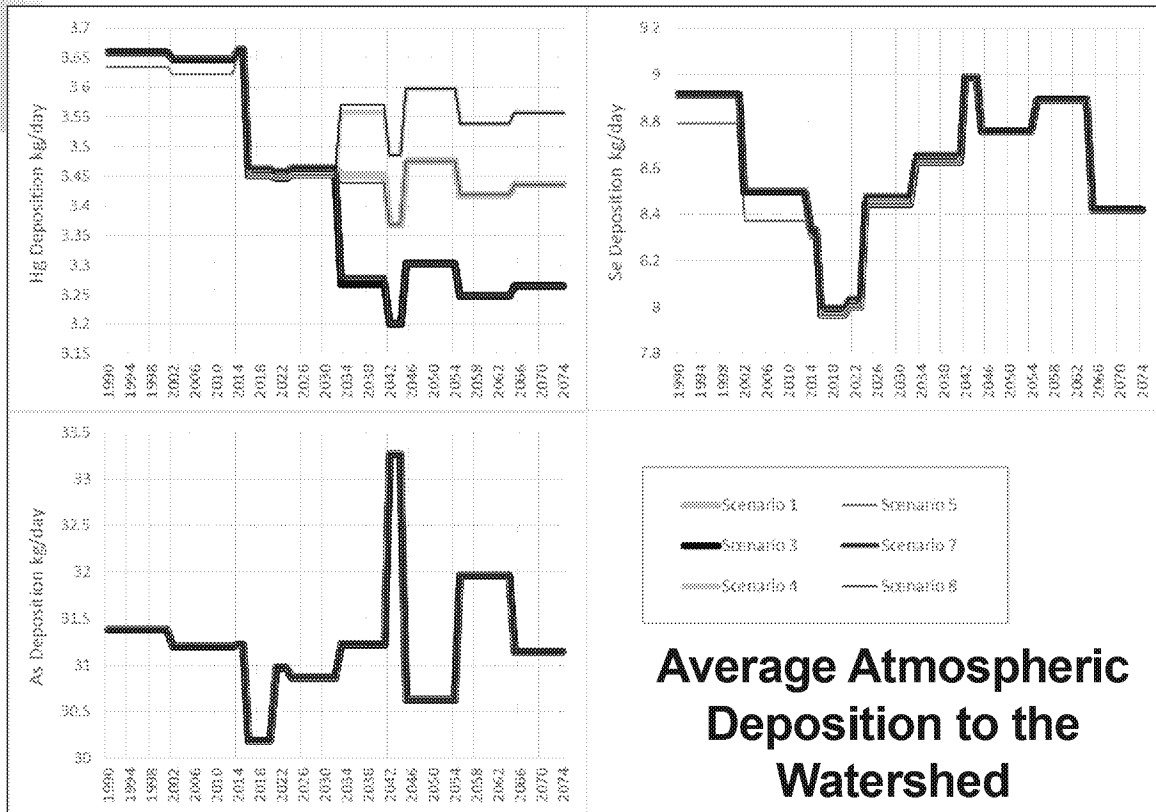


## Simulation Details

- Dynamic simulation run on daily time step
- Maintains volume, mass, heat balances
- Hydrologic parameters simulated:  
flow, depth, velocity, surface elevation, snow  
pack depth, evaporation/transpiration
- Water quality parameters simulated  
temperature, pH, ions (Ca, Mg, K, Na, SO<sub>4</sub>, Cl,  
TIC), nutrients (NH<sub>4</sub>, NO<sub>3</sub>, PO<sub>4</sub>, TKN, TN, TP),  
DO, organic carbon, suspended sediment,  
phytoplankton, mercury, metals

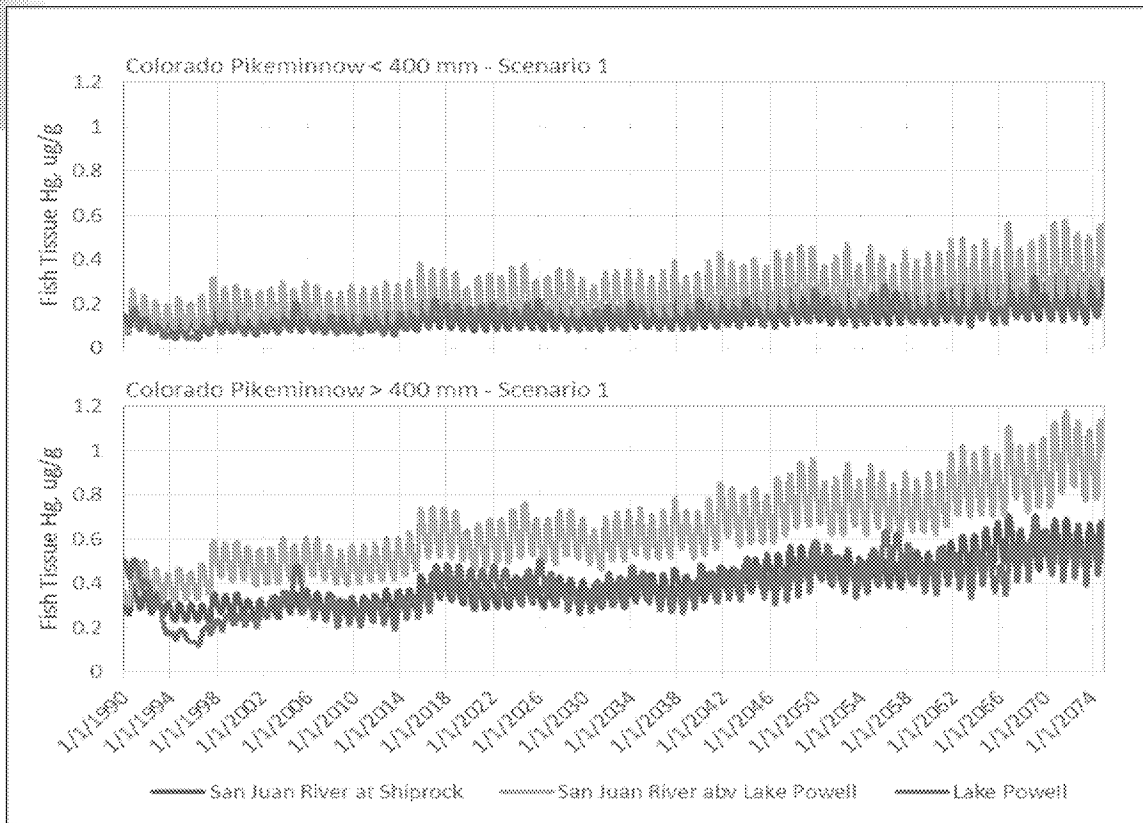
## 6 WARMF Model Scenarios, 1990-2074

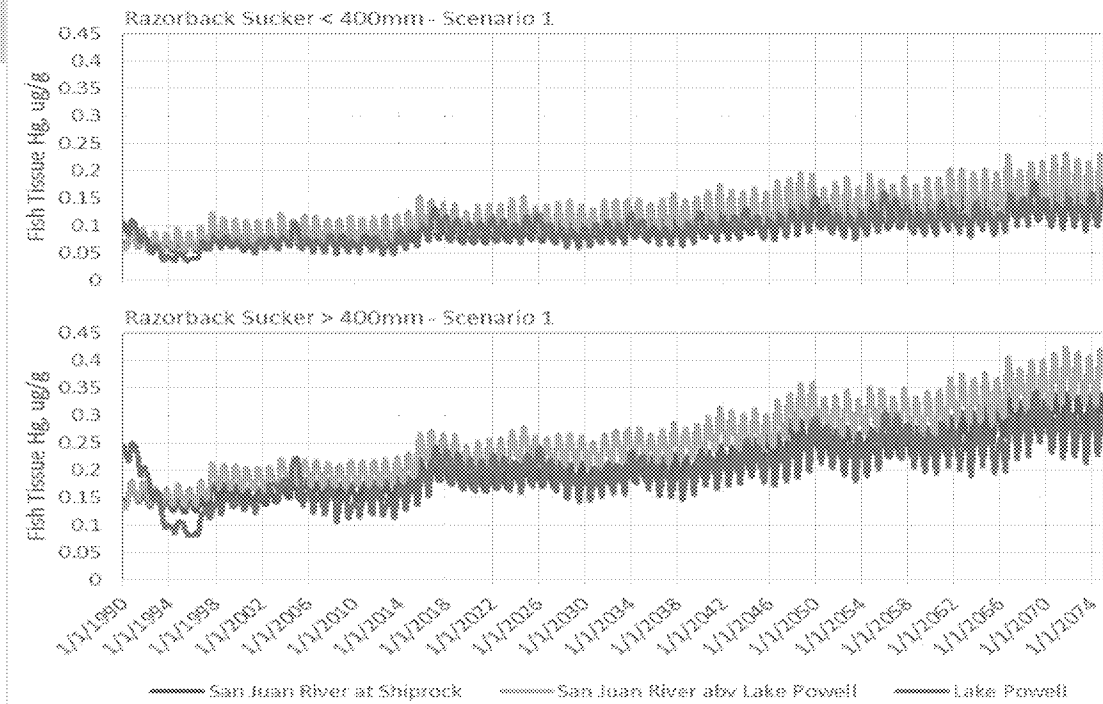
Scenario Name	Four Corners Power Plant	Chinese Emissions
Arizona Public Service (APS) - 1	Base Case – 2042 Shutdown	Base Case - constant
APS – 3	2016 Shutdown	Low Growth Emissions (deposition in U.S. drops)
APS – 4	2016 Shutdown	High Growth Emissions (deposition in U.S. grows)
APS – 5	Never Existed	Base Case - constant
APS – 7	Base Case – 2042 Shutdown	Low Growth Emissions (deposition in U.S. drops)
APS – 8	Base Case – 2042 Shutdown	High Growth Emissions (deposition in U.S. grows)

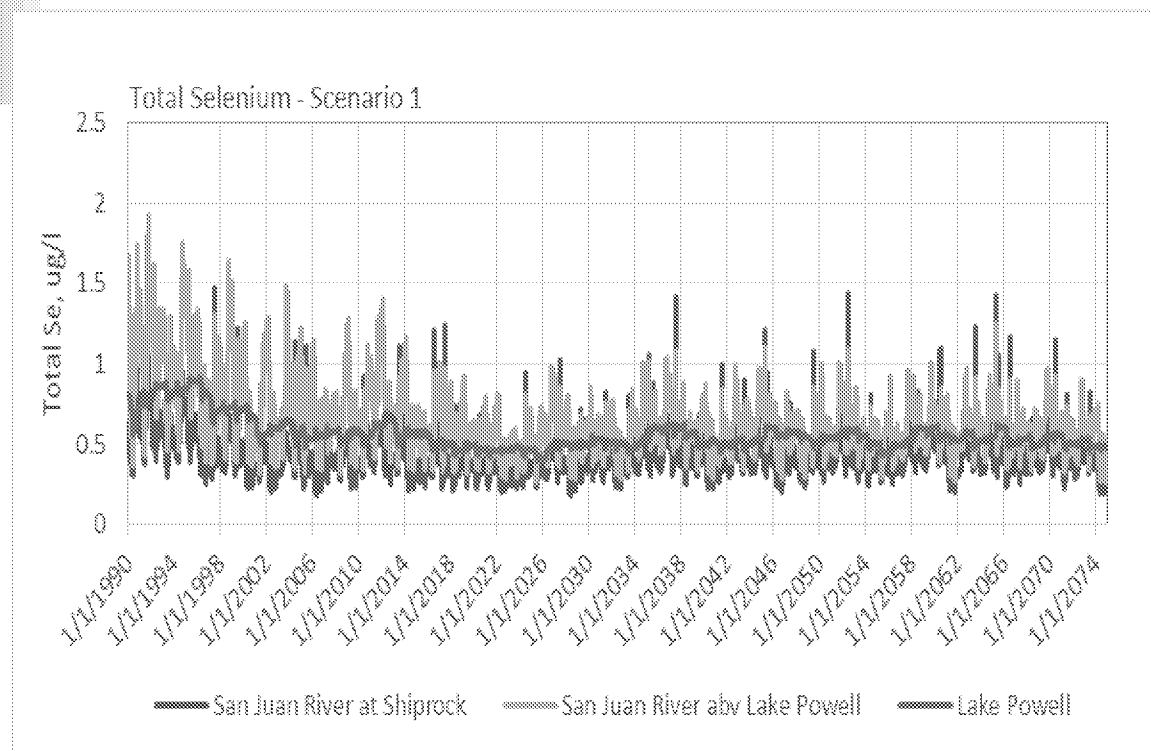


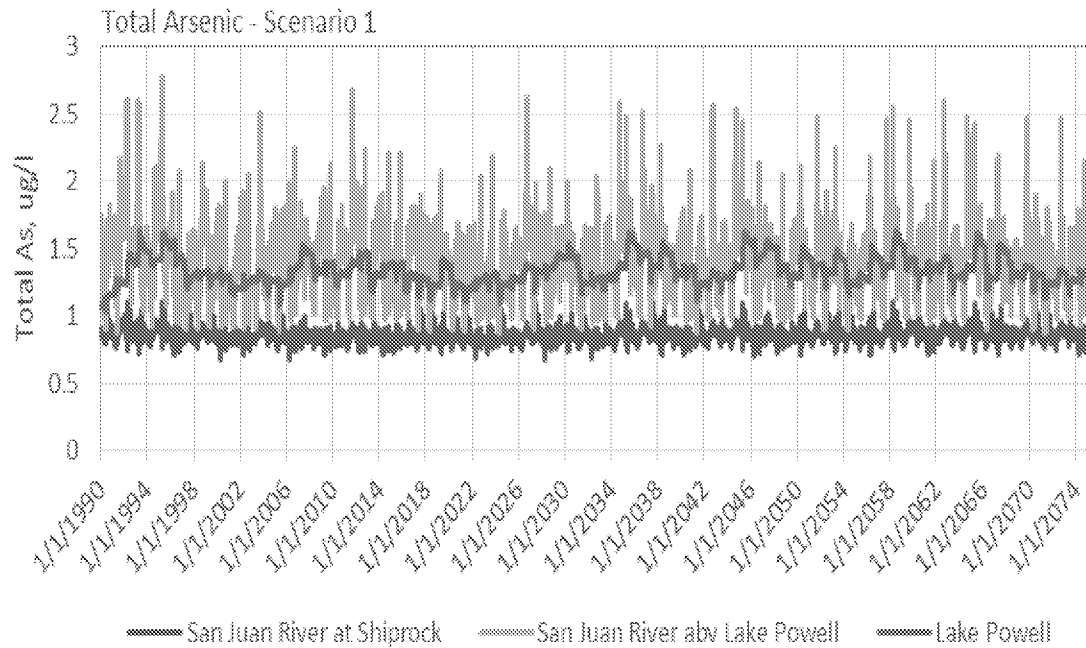
## Projected Future Fish Tissue Mercury Concentrations

- Simulations are for period 1990-2074
- Base case expected future conditions (scenario 1)
- Less than 1% of annual mercury atmospheric deposition ends up in San Juan River/Lake Powell
  - Loss to evasion (back to the atmosphere)
  - Large watershed/waterbody ratio
  - Soil sequestration (accumulation)
- Historical data insufficient to detect trend
  - Model's trend prediction is uncertain
- Future deposition is uncertain











# Scenario Comparisons

Comparison Case	Base Case	Differing Condition	Common Condition
APS – 5	APS – 1	2042 FCPP Shutdown vs. Never Existing	Base Case Chinese Emissions
APS – 7	APS – 1	Base Case vs. Low Growth Chinese Emissions	2042 FCPP Shutdown
APS – 8	APS – 1	Base Case vs. High Growth Emissions	2042 FCPP Shutdown
APS – 3	APS – 7	2016 vs. 2042 FCPP Shutdown	Low Growth Chinese Emissions
APS – 4	APS – 8	2016 vs. 2042 FCPP Shutdown	High Growth Chinese Emissions

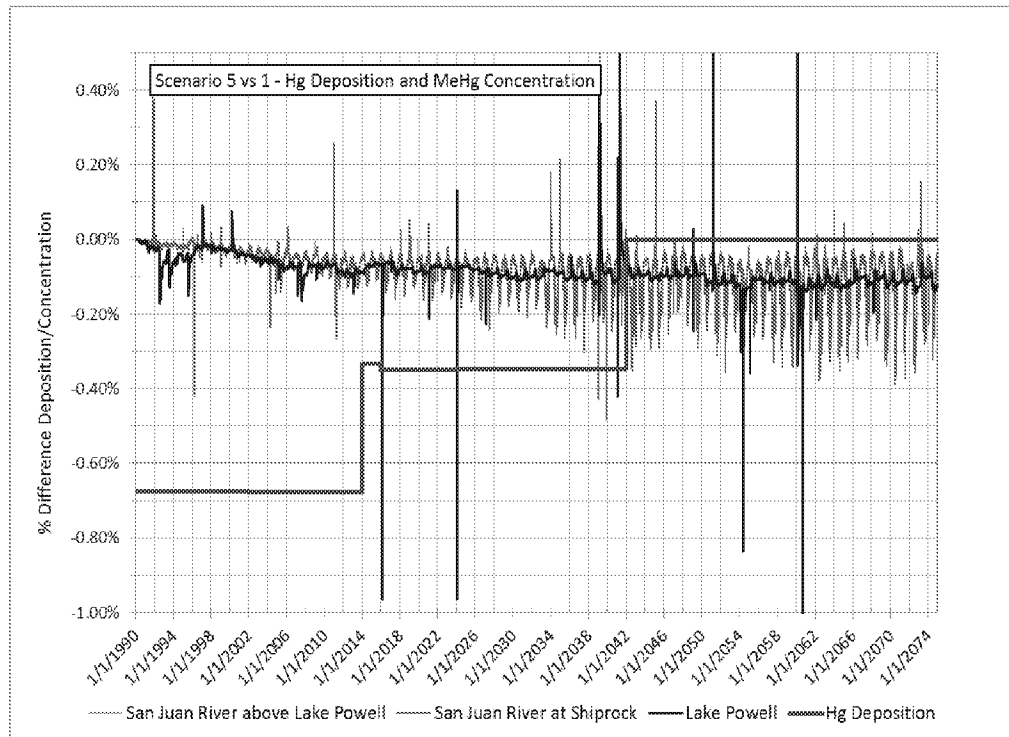
# APS-5 versus APS-1 Results: Mercury

**Common  
Condition**

Mid-range  
Chinese  
Emissions

**Differing  
Condition**

2042 FCPP  
Shutdown  
vs. Never  
Existing



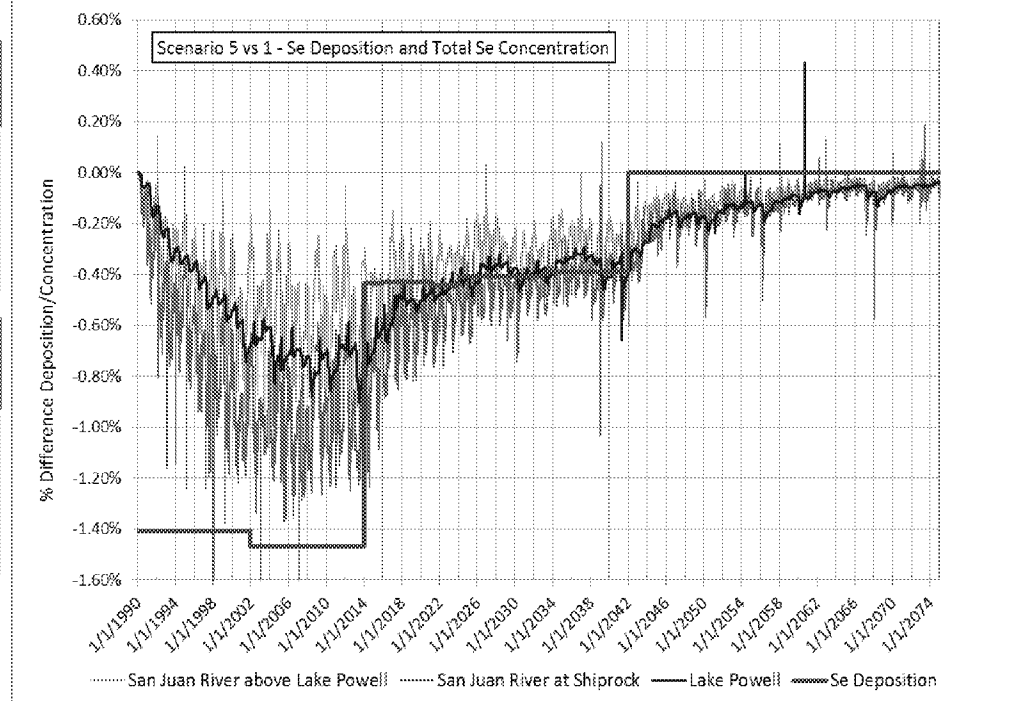
# APS-5 versus APS-1 Results: Selenium

**Common  
Condition**

Mid-range  
Chinese  
Emissions

**Differing  
Condition**

2042 FCPP  
Shutdown  
vs. Never  
Existing



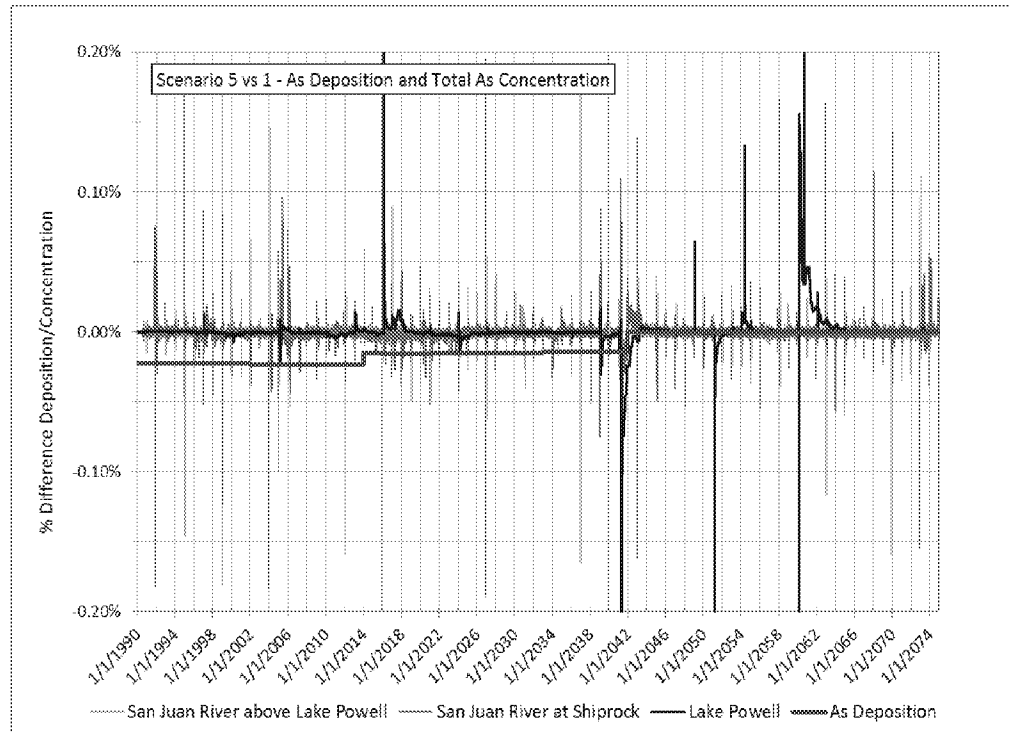
# APS-5 versus APS-1 Results: Arsenic

**Common Condition**

Mid-range Chinese Emissions

**Differing Condition**

2042 FCPP Shutdown vs. Never Existing



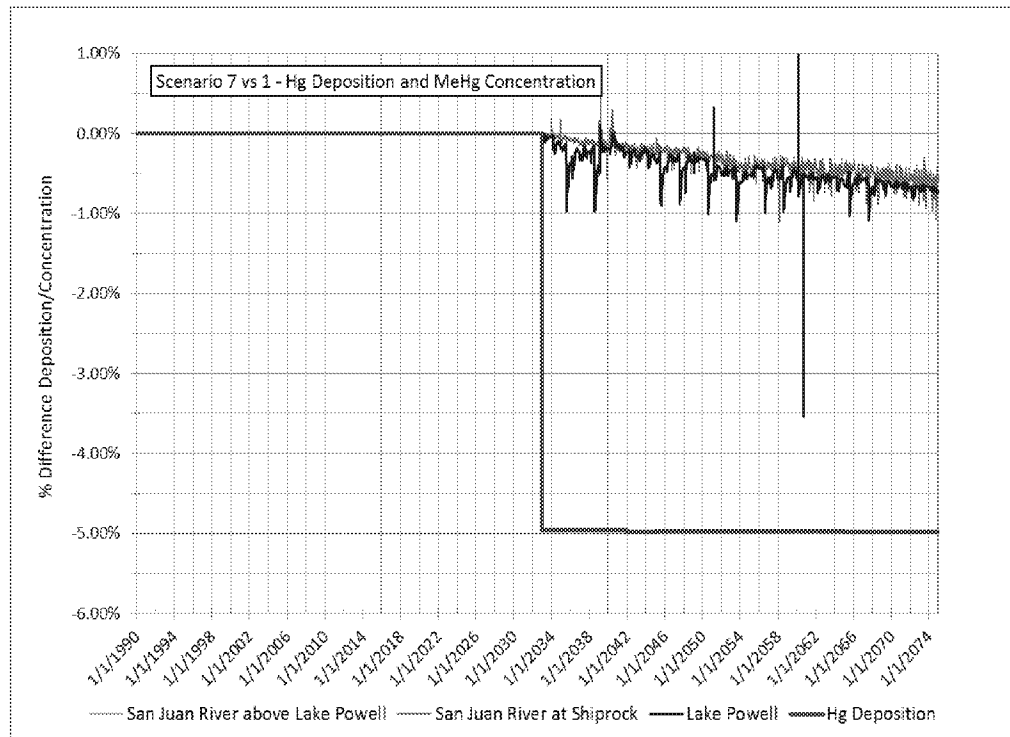
# APS-7 versus APS-1 Results: Mercury

**Common  
Condition**

2042 FCPP  
Shutdown

**Differing  
Condition**

Mid vs. Low  
Chinese  
Emissions



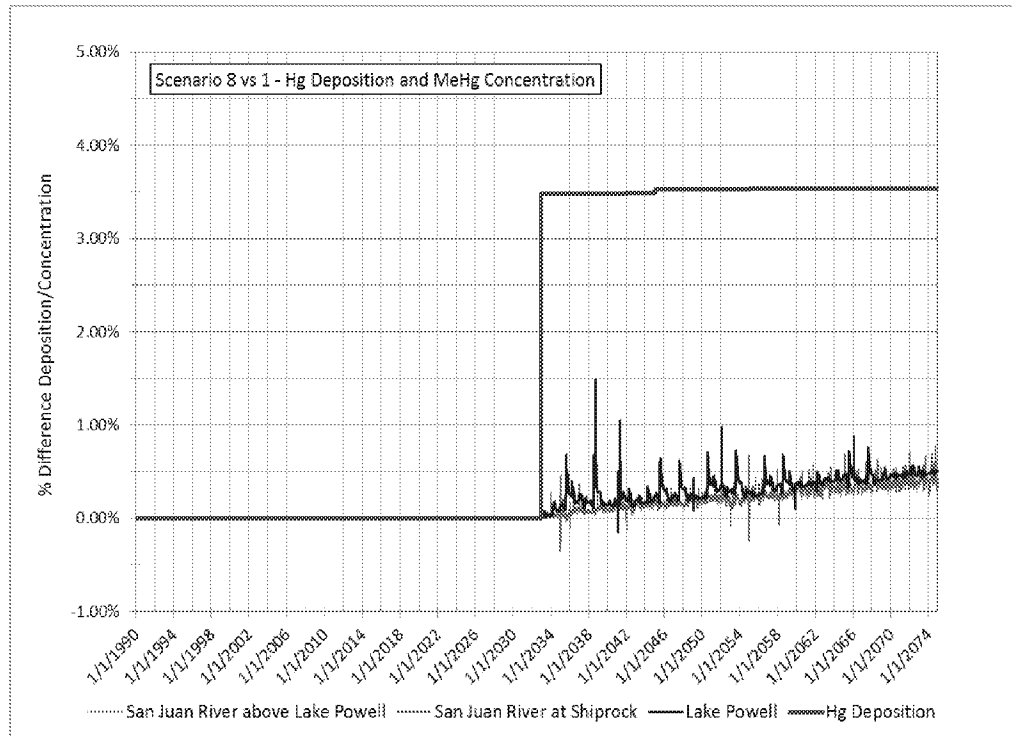
# APS-8 versus APS-1 Results: Mercury

## Common Condition

2042 FCPP Shutdown

## Differing Condition

Mid vs. High Chinese Emissions



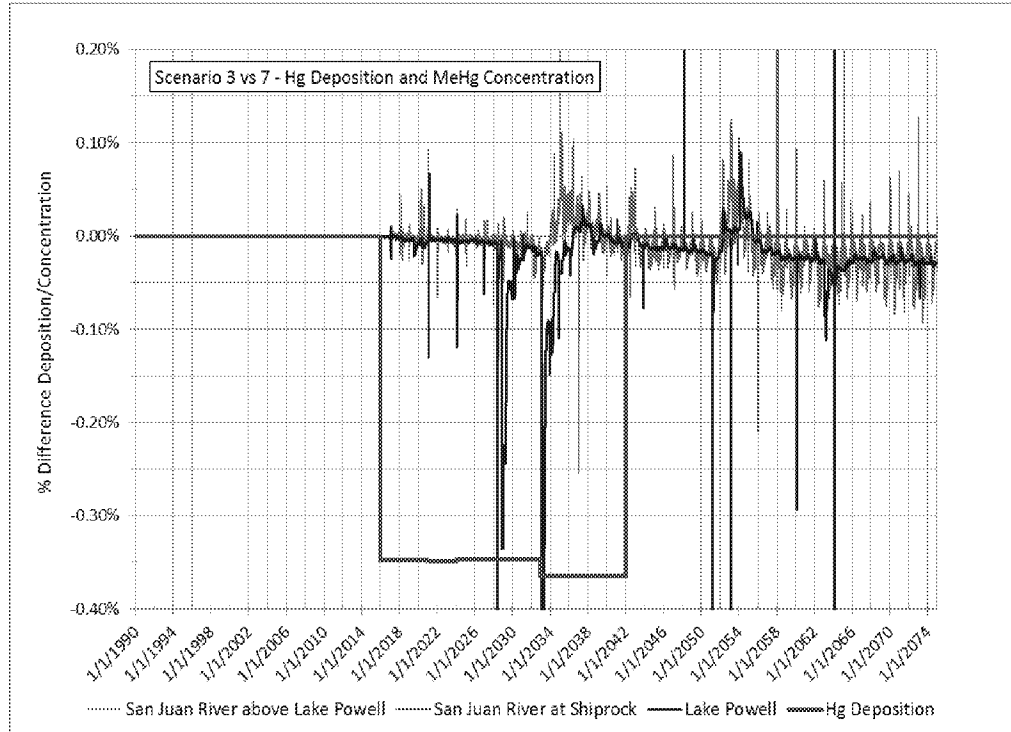
# APS-3 versus APS-7 Results: Mercury

**Common  
Condition**

Low  
Chinese  
Emissions

**Differing  
Condition**

2016 vs.  
2042 FCPP  
Shutdown



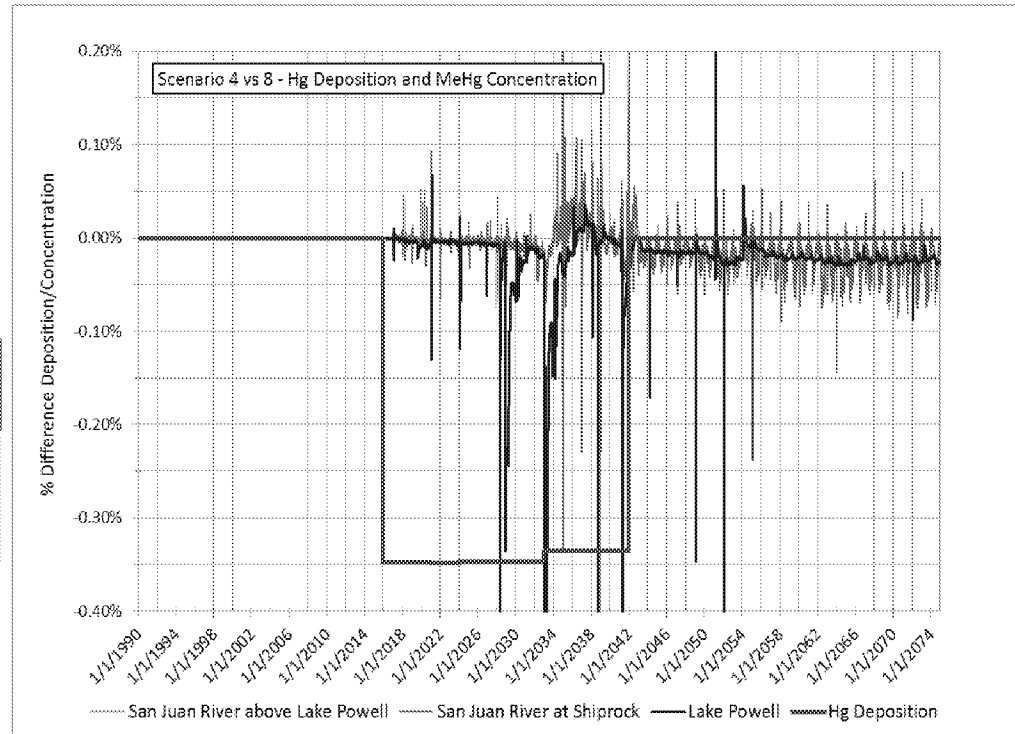
# APS-4 versus APS-8 Results: Mercury

**Common Condition**

High Chinese Emissions

**Differing Condition**

2016 vs. 2042 FCPP Shutdown





## Conclusions: Model Application

- Linkage between CMAQ-APT and WARMF predicts watershed response to air emissions changes
- Linkage can be used to evaluate future conditions, effects of management decisions
- Future trend is highly uncertain
  - Not enough data to discern historical trend, adjust model calibration
- Model has more predictive power when comparing conditions between scenarios (relative changes)

## Conclusions: Simulation Results

- **Effect of Four Corners Power Plant (FCPP) operations:**
  - Mercury
    - <1% of total deposition\* is due to FCPP emissions
    - Watershed & biota responses to changes in emissions & deposition take decades to fully realize
  - Selenium
    - Deposition: >1% currently/<1% after 2015 is due to FCPP
    - Watershed response to changes is more rapid
  - Arsenic
    - <0.1% of deposition is due to FCPP
    - Watershed response almost indiscernible
- **Outcomes can be viewed as “central estimates”** with relatively large uncertainties; limit: lack of long-term observations in SJB

\* Figures are for watershed averages

# QUESTIONS?

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